

Significant event for Romania

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Next month's 'Bucharest 2000' Geophysical Conference and Exposition, 10–14 April being held in the capital city of Romania with support from the EAGE and the SEG marks another important landmark in the development of the geosciences in Romania in the post-1989 political environment for central and eastern Europe. In anticipation of the event, we are publishing two papers due to be presented at the event, which also celebrates 75 years of continuous geophysical prospecting in Romania. Exploration was initiated in 1925 by the Geological Institute of Romania lead by Prof Ludovic Mrazec.

Today the search for oil and gas is being carried out by the Romanian company Prospectiuni and international seismic contractors Schlumberger and Baker Hughes' Western Geophysical. Other research in the geophysical

field is being undertaken by the Geological Institute of Romania, National Institute for Earth Physics, Institute of Geodynamics of the Romanian Academy and GeoEcoMar.

The two papers have been written by some of Romania's most distinguished geoscientists and describe crustal aspects and the geotectonic and geodynamic evolution of Romania as well as the main metallogenic features and prospects for mineral exploration. The papers are unashamedly geological in emphasis but are representative of current work in Romania. Most of the results are based on various geophysical observations, such as deep seismic soundings, magnetotelluric soundings, Bouguer gravity anomalies, aeromagnetic data, ground magnetics and IP electrometry.

Remarks on the metalliferous mineral potential in Romania, focused on future exploration activities

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In the recent Special Issue on 'Qualitative and quantitative metallogenic analysis of the ore genetic units in Romania' published by the Geological Institute of Romania (Borco *et al.*, 1998) it is shown that there are still prospective areas for mineral discoveries, both near-surface and at depth. The most promising targets are situated in 'classic' mining districts or correspond to new metallogenic alignments or/and structures evidenced during the last decade by geological and geophysical surveys. Such mineralizations are generated by epithermal systems, porphyry-epithermal and porphyry systems with Au, Ag, Cu, Pb, Zn ± specific assemblages of trace elements As, Cd, Se, Sb, Tl, Ga, Ge. The latter ones may be recovered directly, during processing activities, or indirectly, during metallurgical processes. Such types of mineralizations are located especially in Neogene volcanics (Metaliferi Mountains and Oas-Gutai Mts.) and possibly, in the Neogene subvolcanic zone and the Gurghiu-Hărghita-Călimani Mountains. They are also related to Banatitic metallogenic alignments and intrusive bodies, Upper Cretaceous-Paleogene

in age, in North Apuseni Mountains, East Carpathians and Banat zone.

Geotectonic and metallogenic setting

Considering the occurrence/distribution of metalliferous deposits within the Romanian territory, the platforms contain only a few ore deposits (Fe and Cu), especially in the Dobrogea region. The mobile geological units are characterized by minor Ba, Cu, Pb, Zn, Fe mineralizations in North Dobrogea area and widespread mineralizations throughout most of the stratigraphic levels of the Carpathian orogen. The complex geological structure of the Carpathians explains the great variety of the genetic/paragenetic metalliferous types which have resulted during a long evolution, from Precambrian to Quaternary. Metallogeny and evolution in association with events of several Wilson orogenic cycles are basic concepts that allow correlations between geological fea-

tures controlling ore deposition with the inherent geochemical behaviour of major metals; this is obvious both for the Upper Paleozoic and the Alpine cycles. As such, Precambrian, Paleozoic and Alpine metallogenetic events are taken into account and reviewed in the following.

The time-stratigraphic depositional sequences correspond to one evident quantitative metallogenetic specialization, specific to the main stages of geotectonic evolution (Table 1). The intensity of mineralization is related to major magmatic events: i.e. acidic and bimodal volcanicity in Lower Paleozoic, granitoids during Upper Cretaceous-Paleocene and volcano-plutonic complexes of intermediate character in Miocene-Pliocene. Ore formation of this kind yielded important deposits of skarn, porphyry and epithermal types and volcanogenic (metamorphosed) type, especially in the East Carpathians, South Carpathians and Apuseni Mountains.

Economic aspects that include the intense mining activity since ancient times and the potential value of mineable reserves and resources show the importance of the following geographic and/or the geologic units: (1) the *East*

Carpathians, with Pb-Zn and Cu ores associated to Neogene volcanics (Oas and Gutai zone) and Cambrian rhyolitic ones (Baia Borsa, Lesul Ursului, Balan ore deposit types); (2) the *Apuseni Mountains* with Au-Ag, Pb-Zn ± Au, Ag and Cu ores associated to Neogene volcanics (Baia de Aries, Zlatna, Brad-Sacaramb districts) and Fe, Cu, Pb, Zn ± Au ores related to the Banatitic magmatism (Baita Bihorului district); (3) western part of the *South Carpathians* proved to be important for Fe accumulations associated to Devonian sub-marine basic volcanism (Teliuc-Ghelar deposit) and porphyry type Cu and Pb-Zn ± Au and Cu mineralizations related to the Banatitic magmatism (Bocsa, Ocna de Fier, Dognecea, Oravita, Ciclova, Moldova Noua ore deposit types). The majority of the Au, Pb, Zn, Cu ± Au, Ag+Cu ore deposits, representative at European scale, have been exploited quasi-continuously from the earliest times. Archaeological and historical data revealed gold exploitation since Late Neolithic time. Ore production has been better organized during the Geto-Dacian (450 BC–106 AD) and the Roman (106–273) historical periods.

Table 1 Quantitative metallogenetic specialization of the main stages of geotectonic evolution

Geotectonic cycles	Commodities	Metals						
		Pb+Zn (%)	Cu (%)	Au+Ag (%)	Fe (%)	Mn (%)	Cu<0.4 (%)	Fe<15 (%)
PROTEROZOIC	Fe, Mn, Pb+Zn, Cu	0.70	0.08	0.02	86.44	12.79	0.00	0.00
CALEDONIAN	Mn, Pb+Zn, Fe, Cu	21.29	9.60	0.02	21.19	47.89	0.00	0.00
HERCYNIAN	Fe, Mn, Pb+Zn, Fe<15(%), Cu	1.64	0.07	0.001	92.58	5.21	0.00	0.49
UNCERTAIN PRE-ALPINE	Fe, Mn	0.00	0.00	0.00	87.36	13.64	0.00	0.00
ALPINE	Fe<15(%), Fe, Pb+Zn, Cu<0.4(%) Cu, Mn, Au+Ag±Ti, V, Mo	7.98	1.88	0.02	35.40	1.25	5.53	47.62
• EXOGENOUS	Fe, Mn, Fe<15(%)	0.00	0.00	0.00	91.27	7.63	0.00	1.05
• ENDOGENOUS	Fe<15(%), Fe, Pb+Zn, Cu<0.4(%) Cu, Mn, Au+Ag±Ti, V, Mo	9.11	2.15	0.03	26.87	0.24	6.32	54.23
• Rifting	Fe<15(%), Fe, Pb+Zn, Cu, Mn	0.28	0.03	0.0001	4.24	0.01	0.00	95.45
• Spreading	Cu	0.00	100.00	0.00	0.00	0.00	0.00	0.00
• Island arc	Pb+Zn, Cu, Mn	4.03	0.39	0.00	0.00	0.10	0.00	79.56
• Subduction	Fe, Pb+Zn, Cu<0.4(%), Cu, Mn, Fe<15(%), Au+Ag	21.29	5.05	0.06	57.31	0.51	15.51	0.17
—Banatites	Fe, Pb+Zn, Cu, Cu<0.4(%), Mn	10.56	7.97	0.004	75.58	0.66	5.12	0.00
—Neogene	Fe, Pb+Zn, Cu<0.4(%), Cu, Mn, Fe<15(%), Au+Ag	29.25	2.89	0.11	43.76	0.41	23.22	0.29
• Collision	Fe, Pb+Zn, Cu, Mn	1.84	1.41	0.004	95.71	1.02	0.00	0.00
• Uncertain source	Fe, Au+Ag, Mn	15.91	0.00	0.30	77.43	6.63	0.00	0.00

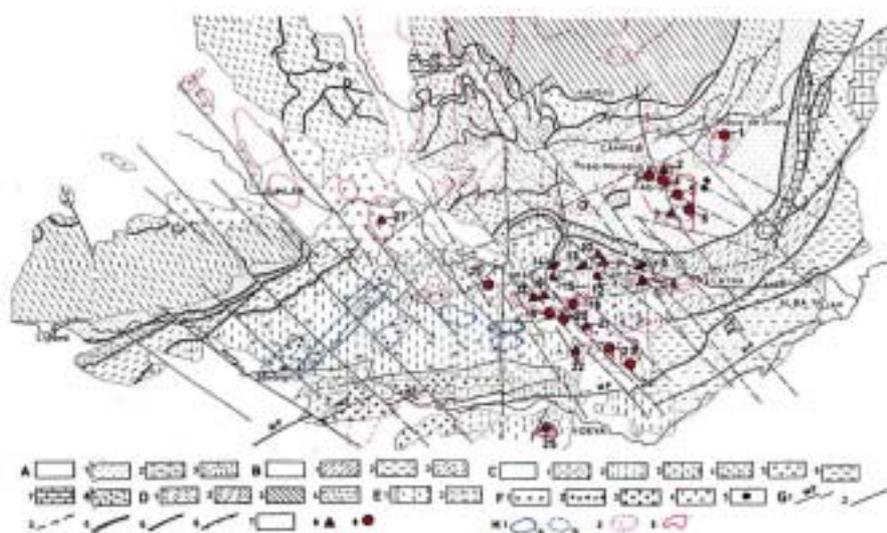


Figure 1 Location of porphyry and epithermal accumulations in the Metaliferi Mountains.

A. Units related to the southern continental margin of the North Apuseni Mts.: 1. Bucium Unit, 2. Grosi Nappe, 3. Frasin Nappe; B. Units related to marginal basins: 1. Fenes Nappe, 2. Valea Mica-Galda Nappe, 3. Cris Nappe; C. Units related to island arc realms: 1. Capalnas-Techereu Nappe, 2. Curechiu-Stanija Unit, 3. Cabesti Unit, 4. Bejan Unit, 5. Hospea Unit, 6. Coltii Trascaului Nappe, 7. Bedeleu Nappe, 8. Rameti Beds—Mesocretaceous post-tectonic cover; D. North Apuseni Mts: 1. Bihor Autochton, 2. Codru Nappes system, 3. Biharia Nappes system, 4. Gosau Formation—post-tectonic cover; E. Units situated on Supragetic and Getic crystalline basement: 1. Rapolt Crystalline, 2. Bozes Nappe; F. Magmatic rocks: 1. Jurassic (ophiolites s.l.), 2. Eocretaceous (granite-granodiorites), 3. Upper Cretaceous-Paleocene (banatites), 4. Neogene (mostly andesitic associations), 5. Pliocene-Quaternary (basalts); G. Conventional signs: 1. Mures Fault (South Transylvanian Fault), 2. fractures system geologically determined, 3. fractures system geophysically deduced, 4. Laramian nappes, 5. Pre-Gosau Nappes, 6. Meso-Cretaceous Nappes, 7. Tertiary molasse, 8. porphyry copper accumulation, 9. epithermal accumulation; H. Alpine plutonic bodies: 1. Eocretaceous magmatites: a. tholeiitic, b. calc-alkaline; 2. Upper Cretaceous-Paleocene magmatites, 3. Neogene magmatites.

Main Neogene ore accumulations: 1. Baia de Aries, 2. Rosia Poieni, 3. Rosia Montană, 4. Rodu-Frasin, 5. Contu, 6. Corabia, 7. Tarnita, 8. Trampoiele, 9. Hanes-Larga, 10. Stanija, 11. Muncaceasca Vest, 12. Magura, 13. Valea Tisei, 14. Rovina, 15. Colnic, 16. Valea Morii, 17. Musariu, 18. Valisoara, 19. Baita, 20. Cainel, 21. Voia, 22. Bolcana, 23. Hondol, 24. Sacaramb, 25. Deva, 26. Caraci-Tebea, 27. Talagiu-Bratosin.

Opportunities for exploration activities

Presently, we can distinguish two groups of targets which can be the object of future research programs: (a) targets based on preliminary exploitation data with minimal reserves and resources, which can justify further detailed programs based on pre-feasibility studies; (b) targets partially revealed by geophysical and geochemical data, which may represent the object of complex prospecting programs.

The huge volume of already existing data will help future exploration programs, using genetic models of ore deposits accumulation.

Targets located in regions with Neogene volcanics

In the *Metaliferi Mountains* (Figure 1), the metallogenesis is related to Badenian and Sarmatian igneous events. Recent investigations suggest that shallow intrusions were responsible for ore formation. The magmatism took place in Tertiary intramontane basins superposed on NW-SE and E-W regional fault systems. The Badenian igneous event yielded Au-Ag epithermal deposits of phreato-magmatic breccia, breccia pipe and vein type. The Sarmatian igneous events yielded porphyry copper systems centered on shallow subvolcanic bodies of andesite to quartz diorite composition. The subvolcanic bodies are located on protuberances of deep-seated diorite plutons and represent the transition to volcanic

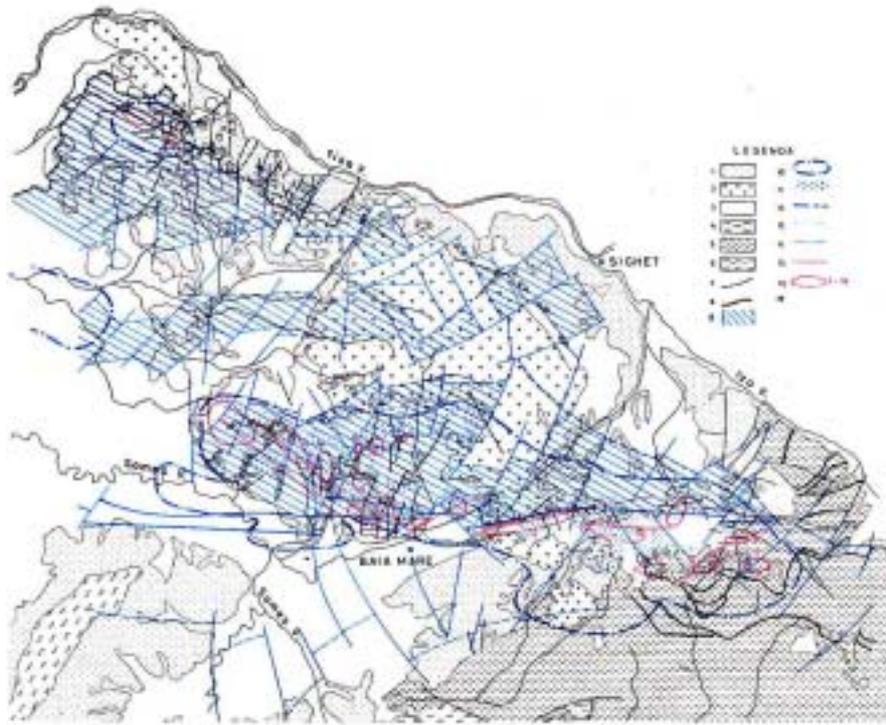


Figure 2 Neogene volcanics in Alpine structural setting of the Oas-Gutai region.

1. Neogene molasse, 2. Post-ore Upper Pontian-Pliocene andesites, 3. Sarmatian-Pontian andesites (metallogenic phase), 4. Badenian volcano-sedimentary formations, 5. Paleogene flysch, 6. metamorphic formations, 7. fault, 8. nappe, 9. tectonic compartments*, 10. Neogene pluton*, 11. pluton culminations*, 12. Dragos Voda transcrustal fracture*, 13. pre-Paleogene fractures partly reactivated*, 14. pre-Neogene fractures partly reactivated*, 15. main metallogenic alignments*, 16. mining fields (1. Racsa, 2. Ilba, 3. Nistru, 4. Sasar, 5. Valea Rosie, 6. Wilhelm, 7. Tyuzosa, 8. Ludovica, 9. Valea Negrii, 10. Dealul Crucii, 11. Herja, 12. Baia Sprie-Suior, 13. Cavnic, 14. Roata, 15. Brainer, 16. Baiut, 17. Varatec, 18. North Baiut, 19. Jereapan).

* Tectonic and metallogenic features located by geophysical surveys

edifices emplaced in the uppermost part of large volcano-plutonic complexes. A part of the porphyry systems exhibits outward radiating veins. In places, gold and base metal epithermal systems that consist of veins are associated with the Sarmatian volcanic-subvolcanic suite. Considering the porphyry-epithermal systems in terms of composition, intensity of mineralization and alterations, the following models may be derived: 1) two models of porphyry copper systems, that is Valea Morii porphyry-epithermal model and Rosia Poieni porphyry with pyrite halo model; 2) the non-porphyry environment is also represented by two models, i.e. the Rosia Montana composite system of breccia pipe and veins and the Săcărâmb vein set.

As a consequence of the intensive exploitation of the rich-est gold and base-metal \pm Au-Ag mineralizations, located in

the upper part of the ore deposits, the exploration activities may be mainly focused on locating other similar accumulations. Excepting Baia de Aries district, in all the districts of the Metaliferi Mountains (Bucium-Rosia Poieni, Zlatna-Stănița, Brad-Săcărâmb and Tălagiu), exploration targets are as follows: (1) the extension of already known ore bodies; (2) disseminated gold in pyrite hosted in porphyry epithermal systems; (3) disseminated gold in pyrite in the upper part of rich epithermal gold deposits exhausted or abandoned (i.e. Hanes, Larga, Muncăceasca, Popa-Stănița, Săcărâmb and Barza deposits); (4) porphyry copper deposits with rich gold content.

In the Metaliferi Mountains, in areas with Badenian volcanic activity, the most important targets are the phreatomagmatic breccia type Rodu and Rosia Montana, with gold-

pyrite disseminations, and some rhyo-dacitic intrusions located by geophysical investigation, situated on the main metallogenic alignment. This NNW-SSE trending alignment, located between Rosia Montana and Contu gold ore deposits, could host epithermal gold mineralizations, situated at a relatively shallow depth.

The *East Carpathians* volcanic arc is developed in the Oas, Gutai, Tibles, Bargău, Rodna, Călimani, Gurghiu and

Hărghita Mountains and resulted from a westward subduction related to the closure of the East Carpathians rift. The epithermal deposits in non-porphyry environment contain base metal and Au-Ag mineralizations.

The Oa° Mts. metallogenic zone (Figure 2) contains mainly base metal and gold veins in the Tarna-Bicsad area. Results of geophysical studies outlined andesitic subvolcanic bodies associated to the metallogenic processes, displaying

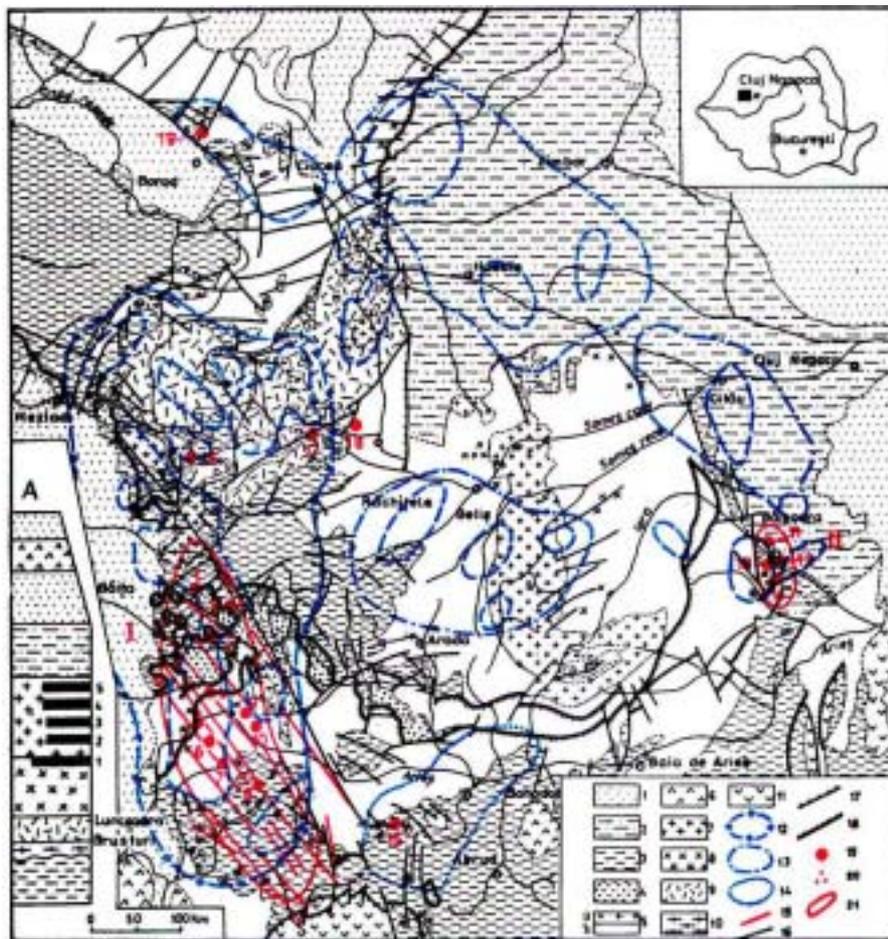


Figure 3 Upper Cretaceous-Paleocene magmatism and metallogenesis in the Alpine structural setting of the Apuseni Mts. region.

1. Tertiary molasse, 2. Paleogene epicontinental formations, 3. Mesozoic sedimentary cover, 4. Permian molasse, 5 a. Granitoids, 5 b. Metamorphic formations, 6. Neogene volcanics, 7. Paleocene granite-granodiorite complex: dacites, andesites; 8. Paleocene quartz-diorites, 9. Paleocene andesite-quartz andesites, 10. Upper Cretaceous rhyodacitic volcano-sedimentary formation, 11. Mesozoic ophiolites, 12. pluton*, 13. intrusive major structures with their culminations*, 14. intrusive structures of intermediary composition*, 15. tectonomagmatic and metallogenic alignments, 16. fault, 17. inverse fault, 18. nappes, 19. main accumulations: 1. Julesti-Valea Fagului, 2. Valea Seaca, 3. Baita Bihor, 4. Izvorul Bihorului, 5. Valea Titisor, 6. Valea Vacii, 7. Brusturi-Luncsoara, 8. Raul Mic, 9. Izvorul Aniesului, 10. Gruiul Dumii, 11. Lita, 12. Masca, 13. Nyerges, 14. Cacova, 15. Sohodol, 16. Budureasa, 17. Valea Boaica, Valea Stanciului, 18. Rachitele, 19. Borod-Cornitel, 20. occurrences, 21. districts.

* Magmatic structures located by geophysical surveys.

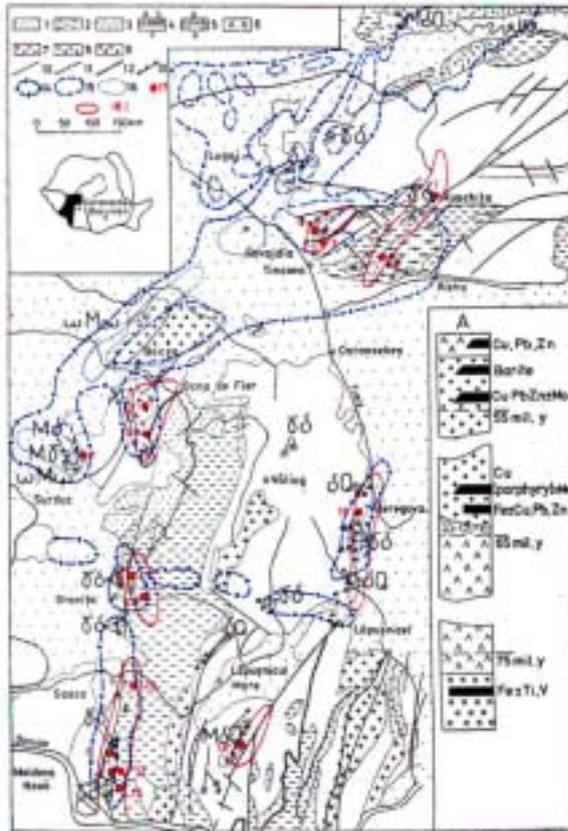


Figure 4 Upper Cretaceous-Paleocene magmatism and metallogenesis in the Alpine structural setting of the West Southern Carpathians.

1. Neogene molasse, 2. Mesozoic sedimentary cover, 3. Permian molasse, 4 a. granitoids, 4 b. basic and ultrabasic rocks, 4 c. metamorphic formations, 5. Upper Cretaceous: a. volcanics, b. volcano-sedimentary formation, 6. diorites, granodiorites, andesites, 7. granites-granodiorites, 8. monzodiorites-monzogranites, 9. gabbros-monzogabbros, 10. fault, 11. inverse fault, 12. nappe, 13. overthrust plane, 14. pluton, 15. pluton culminations of acid composition, 16. pluton culminations of intermediary and basic composition, 17. main ore deposits (1. Ruschita, 2. Ascutita, 3. Valisoara, 4. Tancova, 5. Ocna de fier, 6. Dognenecea, 7. Surduc, 8. Oravita, 9. Ciclova, 10. Sasca Montana, 11. Moldova Noua-Suorov, 12. Moldova Noua, 13. Varad, 14. Lapusnicul Mare, 15. Teregova-Lapusnicel), 18. metallogenetic districts: I. Ruschita, II. Tancova, III. Ocna de Fier-Dognenecea, IV. Oravita, V. Moldova Noua-Sasca, VI. Liliaci-Nasovat, VII. Teregova-Lapusnicel.

typical hydrothermal alteration and mineral occurrences. They may represent good targets for epithermal gold exploration, especially in the Batarci mining field.

In the *Gutai Mts.* (Figure 2) the Baia Mare metallogenic zone is related to a large crustal fault system trending E-W, e.g. Dragos Vodã fault. This regional tectonic feature controls the location of the main ore deposits districts. The epithermal deposits consist of base metal \pm Au, Ag and Au-Ag-quartz-adularia deposits, the hydrothermal systems being associated with a deep-seated quartz-diorite pluton. Variations in metal concentrations with depth are found in important ore deposits such as Ilba, Băita, Baia Sprie and Cavnice. They show a conspicuous vertical zoning Au-Ag \rightarrow Pb-Zn \rightarrow Cu. Porphyry deposits have not yet been found in this setting. In the Gutai volcanics, the most important gold and base metal mineralizations are deposited on pre-Neogene reactivated fractures or in shallow subvolcanic structures, genetically associated to deep plutonic bodies which were located by aeromagnetic anomalies. Two such fracture systems, with intense pre-Neogene magmatic activity and metallogenetic function (Baia Sprie-Suior and Fătutoaia-Purcãret) are of particular importance for possible extensions of already known ore bodies or new veins with disseminated gold and base metal sulfides.

The *Tibles-Bargău-Rodna Mts.* belong to the Neogene subvolcanic zone and contain especially veins with base metal sulfides in the Tibles, Toroiaga and Bargău-Rodna districts. Presently in this area only the Toroiaga subvolcanic andesitic structure offers good prospects, considering the depth extension of the ore deposit, with increasing contents of Cu and Au.

The *Călimani, Gurghiu and Harghita Mts.* are hosting minor mineralizations of siderite (Vlăhita), Hg (Santimbru), base metal sulfides (Dornisoara-Colibita) and sulphur (Călimani), apparently generated by aborted porphyry systems.

Targets located in regions with Laramian magmatism (Banatites)

In Romania, the Laramian or Banatitic belt is developed within the North Apuseni, South Apuseni and South Carpathians subbelts. These subdivisions result from different subduction-related settings, being presently distributed along a major N-S lineament.

The *North Apuseni subbelt* (Figure 3) is characterized by granodiorite \rightarrow granite magmatism and widespread base-metal metallogenesis. Two metallogenetic zones have been recognized: (1) the inner zone exhibits a complex metallogenesis in the Bihor-Gilau Mts. It contains Fe, Mo, Bi, W, Cu, U, Co, Ni, Pb, Zn, B, Au and Ag ores in skarns, stratiform bodies and veins in the Băisoara, Băita Bihorului and Luncoara-Brusturi-Poiana districts. Băita Bihorului is the most impor-



tant deposit. The ore zoning around the pluton is Mo → Bi-W-Cu → U → Pb-Zn → B and is expressed in a vertical column extending up to 1.5 km away from the granite pluton. Calcic and magnesian skarns contain molybdenite, bismuthinite, Bi sulfosalts and tellurides, scheelite, Cu minerals, galena, sphalerite, szaibelyite, ludwigite, fluoborite, and kotoite. Metasomatised detrital hornfelses (epidote + chlorite + actinolite, albite + quartz, and sericite + quartz associations) contain U and Cu in stratabound lenses and molybdenite in impregnations and veinlets, whereas Paleozoic detrital rocks and crystalline schists situated far from the pluton enclose bands and veins of common sulfide ores. The same granitic intrusion yielded 'pentametallic' (U, Ag, Ni, Co, Bi) ores in veins and Cu-U ores as stratiform disseminations at Avram Iancu and base metal ores at Brusturi and Luncsoara; 2) the outer zone noted for base metals, is located in the Vlădeasa Massif. Hydrothermal Pb-Zn ores occur in the Scind-Răchitele and Bucea-Cornitel districts. In this zone, geophysical data evidenced base-metal and Au-Ag mineralizations only at deeper levels and associated to hypabissic subvolcanic bodies.

The *South Carpathians* (Banat-Poiana Rusca Mts.) subbelt (Figure 4) consists of two zones that are parallel to a suture-like contact between two crustal blocks that collided during Laramian deformation: (1) the inner zone, located in the South Banat Mts., exhibits a monzodiorite or diorite → granodiorite magmatism and related Cu-Mo porphyries that

occur at Moldova Nouă and Sasca; 2) the outer zone in the North Banat-Poiana Rusca Mts. exposes granodiorite → granite magmatism with Fe, Cu, Pb-Zn skarn deposits at Dognecea and Ocna de Fier and Mo-W-Cu skarn deposits at Oravita.

This zone may be important for porphyry copper + skarns ore deposits in the Vărad-Oravita district, as well as for gold disseminations, possibly in the halo of ore deposits such as Ocna de Fier-Dognecea or in the Oravita district.

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